PCT

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: PRINTING SYSTEM AND INK JET NOZZLE CONTROL METHOD AND APPARATUS HAVING COMPENSATION FOR MALFUNCTIONING NOZZLES
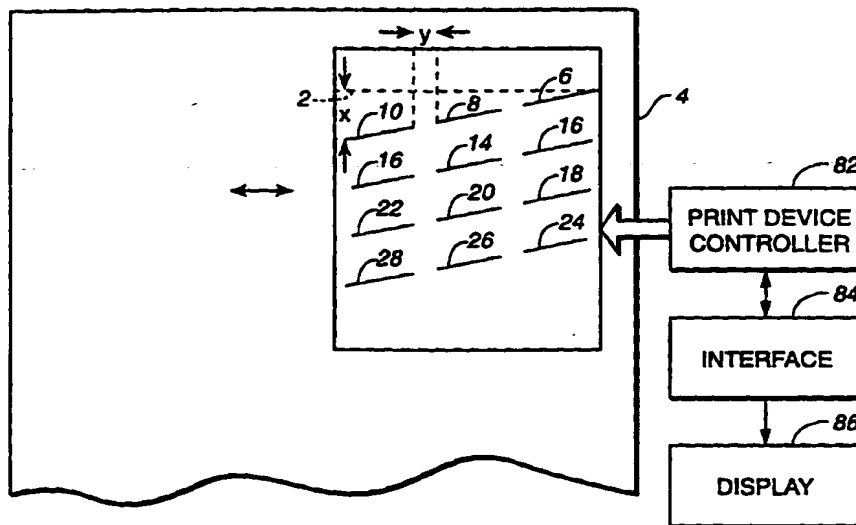
(57) Abstract

The present invention is directed to controlling an ink jet printing device during an interleaved, or overlap, mode of operation. A printing device (2) configured to scan back and forth across a printing medium (4) includes a plurality of ink jet print heads (6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28). Ink jet nozzles of the print heads which would normally be inoperative during a given scan of the printing device are selectively activated by a print device controller (82) to compensate for nozzles determined to be inoperative.

PRINTING SYSTEM AND INK JET NOZZLE CONTROL METHOD AND APPARATUS HAVING COMPENSATION FOR MALFUNCTIONING NOZZLES

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to control of a printing device, and

5   more particularly, to the control of such a device during printing in an interleaved

mode.

State of the Art

Printing devices, such as ink jet printing devices, are well known. These

types of printers are available from, for example, Hewlett Packard and ENCAD. As

10 those skilled in the art will appreciate, ink jet printers often include at least one non-

interleaved, or non-overlap mode of operation wherein no overlap of the print device

over earlier printed bands occurs. Further, these devices include at least one

interleaved, or overlap, mode of operation. To better assist in an understanding of

the present invention, a brief review of an overlap mode of operation will be

15 provided.

A typical ink jet printing device includes plural print heads, each of which

includes a plurality of ink jet nozzles. The plural ink jet nozzles associated with a

given color of printing ink can be displaced from one another in a vertical direction.

In a non-overlap mode of operation, all of the ink jet nozzles are operated to print a

20 continuous band as the print head is moved across a printable medium. Each pass of

the print head across the printable medium (e.g., sheet of paper) constitutes a printed

band. In the non-overlap mode, the print head is repeatedly scanned back and forth

across the sheet without overlapping a previously printed band.

In contrast, in an overlap mode, the print head is controlled such that a given

percentage of the print head, and thus the ink jet nozzles, overlap a previously

printed band on the sheet (e.g., 25% or 50% of the nozzles in the print head overlap

a previously printed band). As such, each area of the sheet is printed using multiple

5   scans with different portions of the print head or heads. Such a technique is

considered to improve the consistency of a printed image.

One drawback associated with conventional ink jet printing devices,

regardless of whether they operate in an overlap mode or in a non-overlap mode, is

that when one or more ink jet nozzles malfunctions, undesired inconsistencies can

10   result in a printed image. This can be disastrous to a production run. It would

therefore be desirable to provide some method and device which can account for the

occurrence of malfunctioning ink jet nozzles without requiring discontinuation of the

printing operation.

SUMMARY OF THE INVENTION

15   Exemplary embodiments of the present invention are directed to a method and

apparatus for controlling an ink jet printing device during an interleaved, or overlap,

mode of operation to compensate for malfunctioning ink jet nozzles. According to

exemplary embodiments, when one or more ink jet nozzles is detected to be

malfunctioning, ink jet nozzles which would not normally be used during a given

20   scan of the print head are selectively activated to compensate for malfunctioning

nozzles.

Generally speaking, exemplary embodiments relate to a method and apparatus

for controlling ink jet nozzles of a printing device, by identifying ink jet nozzles in

the printing device which have malfunctioned; and by controlling the output of

remaining ink jet nozzles in the printing device to compensate for said malfunctioning

ink jet nozzles.

BRIEF DESCRIPTION OF THE DRAWINGS

5   Other objects and advantages of the present invention will become apparent

from the following detailed description of preferred embodiments when read in

conjunction with the accompanying drawings, wherein like elements are designated

by like reference numerals, and wherein:

           Figures 1A-1B show a print device and control system therefor, as well as a

10 test image produced to detect malfunctioning nozzles;

           Figures 2A-2C illustrate an overlap mode in accordance with an exemplary

embodiment of the present invention;

           Figure 3 illustrates a 25% overlap mode of operation in accordance with an

exemplary embodiment of the present invention;

15   Figures 4A-4C illustrate scan masks for use in ink jet nozzle control

according to an exemplary embodiment of the present invention; and

           Figures 5A-5C illustrate look-up tables for implementing compensation of

scan masks in accordance with exemplary embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

20   Figure 1A illustrates a print head and print head control system which can be

used in accordance with exemplary embodiments of the present invention. In the

exemplary Figure 1A illustration, a print device having at least one print head is

positioned over a sheet 4 of printable material (e.g., paper). Components used to

mount the print device do not constitute part of the present invention and are

therefore not illustrated in Figure 1A for purposes of simplifying the drawing.

The print device 2 of Figure 1A is shown to include plural print heads. While

any number of print heads can be included on the print device 2, for purposes of

5 simplifying the following discussion, 12 print heads labelled 6-28 are illustrated. In

an exemplary embodiment, the three print heads 6, 8 and 10 are associated with a

first color (e.g., black). The second row of three print heads 12, 14 and 16 are

associated with a second color (e.g., yellow). A third row of print heads 18, 20 and

22 are associated with a third color (e.g., cyan). A fourth row of print heads 24, 26

10 and 28 are associated with a fourth color (e.g., magenta). Although three print heads

are shown with respect to each color, those skilled in the art will appreciate that any

number of such print heads can be associated with each color. Further, those skilled

in the art will appreciate that any number of rows of print heads can be used to

accommodate any number of different colors (e.g., six color printing can be

15 implemented by adding additional rows of print heads).

The print device 2 is configured to scan back and forth horizontally across a

printable medium, such as the sheet 4, and can be configured to print in both

directions. To better understand the following discussion, an exemplary operation of

the print heads will be provided.

20 Each of the print heads 6-28 includes a number of ink jet nozzles. For

example, each of the print heads can be configured to include 128 such nozzles

arranged along the length of the print head. When viewing the print heads associated

with a given color (e.g., the print heads 6, 8 and 10 associated with the color black)

in a vertical direction of Figure 1A, the print heads are aligned such that the

lowermost nozzle of the print head 6 is above the uppermost nozzle of the print head

8. Similarly, the lowermost nozzle of the print head 8 is located above the

uppermost nozzle of the print head 10. Each row of print heads (i.e., the lower rows

5   associated with the remaining colors, yellow, cyan and magenta) are similarly

configured.

In a non-overlap mode of operation, a printed band would be produced on the

sheet 4 by traversing the print device 2 across the sheet, with ink jet nozzles being

selectively activated. For example, to produce a solid black band, all 128 ink jet

10   nozzles in each of the print heads 6, 8 and 10 would be activated. Because the ink jet

nozzles do not overlap in a vertical direction, a solid band would be produced as the

print device 2 scans across the sheet, and this band would have a vertical height

labeled "x". Note that the height "x" of the band is defined by the vertical span

between the location of the uppermost nozzle of the print head 6 and the lowermost

15   nozzle of the print head 10. A solid band of the colors yellow, cyan and magenta

could be produced during the same scan in similar fashion to print four different

color bands in one scan.

As those skilled in the art will appreciate, as the print device 2 scans back and

forth across the paper. The print device 2 can be controlled to print in both

20   directions. With each scan, the print device 2 moves downward in the vertical

direction and/or the sheet 4 is moved upward, with the total relative movement

between the print device and the sheet corresponding to one band. The various ink

jet nozzles in the print heads 6-28 can be selectively controlled to lay down drops of

ink of a given color at precise locations on the sheet, and thereby print a desired

image of high resolution. The composite of these dots on the page results in the

production of any desired image on the sheet 4.

In an exemplary embodiment, the print heads associated with a given color

5   (e.g., the print heads 6, 8 and 10 associated with the color black) can be separated

from one another in the horizontal direction by a predetermined width labelled "y" in

Figure 1A. The separation instance "y" can be provided between each of the print

heads in the remaining rows of print heads for the colors yellow, cyan and magenta.

The present invention is not limited to any specific configuration of a print

10   device. For example, a print device which includes a single vertical column of ink

jet nozzles, or which includes a single horizontal row of ink jet nozzles can be used.

The nozzles can be used for monotone printing or can be separated into multiple

groups wherein each group prints a different color. Alternately, multiple horizontal

rows or vertical columns of ink jet nozzles can be used, wherein the nozzles of each

15   row or associated with a different color ink. Numerous other variations in the print

head configuration will, of course, be apparent to those skilled in the art.

As those skilled in the art will also appreciate, the ink jet nozzles themselves

do not constitute a part of the present invention, and are readily available from such

manufacturers as Hewlett Packard. For example, the nozzles can be piezoelectric

20   controlled nozzles which can vary in their specifications with respect to their ink

spray, or "firing", rate. This rate dictates the speed with which the scanning can be

implemented. That is, the rate with which an ink jet nozzle can create a drop of a

given size (or volume) on a sheet will dictate the speed with which the scan head can
be moved across the sheet.

Having described an exemplary print device, an exemplary method and device
for controlling ink jet nozzles of such a print device in accordance with the present
5   invention will now be provided. According to a first step of an exemplary method of
the present invention, a test phase is performed to detect and identify any ink jet
nozzles which have malfunctioned. There are numerous ways in which a
malfunctioning ink jet nozzle can be detected. In accordance with an exemplary
method, a user interface is provided for identifying any non-working ink jet nozzles
10   during a test run of the print device across the sheet 4 in a non-overlap mode (e.g., a
mode wherein all 128 ink jet nozzles of each print head are sequentially activated at a
predetermined time).

Referring to Figure 1B, malfunctioning ink jet nozzles can be identified by
activating a scan of the print device 2 across the sheet 4 to produce a plurality of
15   print lines (i.e., one print line for each print head). The print lines are produced by
sequentially activating the nozzles of each print head for a predetermined period of
time, as represented by time increments t_1, t_2, t_3 and so forth. This process can be
performed in parallel for each print head.

Figure 1B illustrates the lines produced on sheet 4 by sequential activation of
20   the ink jet nozzles in each print head during a single scan of the print device 2 across
sheet 4 from right to left. As shown in Figure 1B, the ink jet nozzles of each offset
print head in the print device 2 are controlled so that the printing of each of the test
lines 58-80 begins in vertical alignment with an imaginary, dashed line 30. In the

Figure 1B example, the sheet 4 is not moved during the printing of the line segments in this test phase. Therefore, each individual segment is horizontal, but is stepped one pixel down relative to a previously printed, adjacent segment as shown in Figure 1B.

5   In an exemplary test phase for identifying malfunctioning ink jet nozzles, note that it is the uppermost nozzle for each of the print heads 10, 16, 22 and 28 which will first print at the imaginary vertical line 30 in Figure 1B (i.e., assuming the print device 2 is scanning from right to left). Accordingly, the uppermost ink jet nozzle in each of the print heads 10, 16, 22 and 28 is activated from a time t0 until a time t_1 to

10   produce a first printed segment for each of the colors: black, yellow, cyan and magenta. That is, the uppermost nozzle of the first print head 10 is activated from time t0 until time t_1 to produce a first printed segment 32 on the sheet 4 of Figure 1B. The uppermost nozzle of the print heads 16, 22 and 28 similarly produce the printed segments 34, 36 and 38 from time t_0 until time t_1.

15   Although the first nozzle for each of the print heads 10, 16, 22 and 28 is shown to have produced a respective printed segment 32, 34, 36 and 38 in Figure 1B, those skilled in the art will appreciate that if any one of these nozzles had not been operating, a segment would not have been produced in Figure 1B. For example, if the first nozzle of print head 10 is malfunctioning, the location on printed

20   sheet 4 where segment 32 was to have been printed would be blank. As will be apparent from a later discussion, this will be used to detect when a printed nozzle is malfunctioning, since the absence of a printed segment at a particular location on the sheet 4 can be correlated to a particular ink jet nozzle in the print device 2.

The foregoing operation is repeated for each ink jet nozzle in each of the print

heads. As the print device 2 continues to scan to the left hand side of Figure 1B, the

next sequential ink jet nozzle on each of the print heads 10, 16, 22 and 28 is activated

from time t1 to time t2. This process is repeated until all ink jet nozzles of each

5   printed head have had an opportunity to print a segment at a predetermined location

on sheet 4.

It will be further apparent to those skilled in the art that as a subsequent print

head associated with a given color crosses the imaginary vertical line 30, its

uppermost ink jet nozzle will be activated. In the exemplary illustration of Figure

10   1B, it is assumed for purposes of this discussion that at time t6, the uppermost ink jet

nozzle of the print heads 8, 14, 20 and 26 has reached the imaginary vertical line 30.

Accordingly, at time t6, the sixth ink jet nozzle of the print heads 10, 16, 22 and 28

is activated to produce a respective segment. Similarly, the uppermost ink jet nozzle

for each of the print heads 8, 14, 20 and 26 is activated at time t_6 to produce printed

15   segments 48, 50, 52 and 54. As the print device 2 continues to scan from right to

left across the sheet 4, the nozzles of the various print heads are sequentially

activated. By the time a given print head reaches another imaginary vertical line 56

located on the left hand side of Figure 1B, all ink jet nozzles of that print head have

sequentially been activated for a predetermined period of time to produce one of the

20   horizontal printed lines in Figure 1B.

The exact timing associated with the control of the ink jet nozzles to produce

the Figure 1B segment, will be apparent to those skilled in the art and need not be

described in detail. This timing will, of course, be a function of the speed with

which the print head is scanned across the sheet, and the relative spacing between the

print heads. It will be further appreciated that where a single print head having a

single vertical column of nozzles is used for each color ink, the respective nozzles for

each column (i.e., for each color) will be activated at the same time to produce the

5   line segments used during the test phase to detect malfunctioning nozzles. As those

skilled in the art will appreciate, it is only necessary that all nozzles of the print

device be activated to print at some time so that malfunctioning nozzles can be

properly identified.

Because each exemplary print head of the Figure 1A embodiment includes

10   128 nozzles, each printed stepped line of Figure 1B (e.g., stepped line 58 produced

by print head 6) includes 128 segments, each segment having been printed by a

respective one of the ink jet nozzles. The stepped line 60 corresponds to 128

segments sequentially produced by the 128 ink jet nozzles of the print head 8. The

horizontal line 62 corresponds to 128 segments sequentially produced by the ink jet

15   nozzles of the print head 10.

Similarly, stepped lines 64, 66 and 68 correspond to stepped lines produced

by the print heads 12, 14 and 16, respectively. Stepped lines 70, 72 and 74

correspond to stepped lines produced by the print heads 18, 20 and 22, respectively.

Stepped lines 76, 78 and 80 correspond to stepped lines produced by print heads 24,

20   26 and 28, respectively.

As mentioned above, if any nozzle was malfunctioning, a gap will exist in a

horizontal line associated with a location in the Figure 1B test line where that nozzle

should have been printing. For example, assume that segment "z" of the horizontal

line 80 corresponds to a location where the 95th ink jet nozzle of the print head 28

should have been printing. The absence of ink in this segment can be correlated by a

user interface 84 (Figure 1A) to the 95th nozzle of the print head 28 to identify the

malfunctioning nozzle to the user. The user interface can be configured to correlate a

5   missing segment to a particular nozzle automatically. Alternately, the user can be

prompted to review the printed line segments (e.g., graphically review the test print)

and then enter identification information (e.g., nozzle number) of any malfunctioning

nozzles.

In accordance with an exemplary embodiment, the signals used by a print

10 device control 82 to activate each nozzle of the printing device 2 in known fashion

can be directed to the user interface 84. The user interface can receive these signals,

and simulate the horizontal lines of Figure 1B on a computer display 86, wherein

nozzle numbers are correlated on the display 86 with the line segments. Alternately,

the user can input the malfunctioning nozzle information. By viewing a graphical

15 print and/or the display, the user can easily identify missing line segments. The user

and/or the user interface can record those ink jet nozzles which are malfunctioning in

a recording (e.g., digital memory) device. The malfunctioning nozzle information

(i.e., the identification of the ink jet nozzles which are malfunctioning) can then be

stored and processed to control the printing device via print device control 82 in a

20 manner which compensates for malfunctioning ink jet nozzles.

Those skilled in the art will appreciate that other techniques for detecting

malfunctioning ink jet nozzles can, of course, be used. For example, optical

detection means (e.g., a charge-coupled device (CCD) camera) can be used in

conjunction with the print device to optically identify those ink jet nozzles which are

not operating properly. In an embodiment where such a camera is included at the

printer location, the printer will already have information regarding the location of

bad nozzles (e.g., by indexing a position of the camera to the nozzles being observed)

5   and therefore doesn't need to send the information to the display identify and record

malfunctioning nozzle information.

Once malfunctioning ink jet nozzles have been detected, identified and

recorded, subsequent steps in accordance with an exemplary embodiment can be

implemented to control the remaining, properly functioning ink jet nozzles to

10   compensate for malfunctioning nozzles. Generally speaking, exemplary

embodiments of the present invention operate the print device in an interleaved, or

· overlap, mode of operation, wherein less than 100% of the dots in a band are printed

during each of the print head over the band on the sheet 4. During a subsequent

scan, different nozzles of the print device are scanned over the band to print dots

15   which were not printed during the first scan. In accordance with the present

invention, nozzles which are properly functioning can be used during the subsequent

scan to print areas of the band that should have been printed by the malfunctioning

nozzles during the earlier scan (or vice versa).

Before discussing compensation for malfunctioning nozzles, a brief review of

20   a 50% overlap mode and a 25% overlap mode will be provided. Referring to Figure

2A, printing in a 50% overlap mode will be discussed. During a first scan, or pass,

of a printing device over a sheet, special print control is used; that is, printing is

performed to produce an initial band 202 using less than all of the nozzles associated

- 12 -

with the print heads provided for the color magenta. In this initial pass the lower

half of the 384 nozzles in the print heads 24, 26 and 28 is used to print the first scan

of the first band on the sheet After this initial scan, all 384 nozzles are used during

subsequent scans, with the uppermost nozzles filling in unprinted dots of the first

5   scan, and with the lowermost nozzles printing the first scan of a subsequent band.

Thus, after the initial band has been printed, the relative vertical position of the print

device and the sheet is adjusted so that the upper half of ink jet nozzles are located

over the band 202 for purposes of implementing a second pass over the band. For

example, where 384 nozzles are used for each color, the print device and/or the sheet

10   are stepped relative to one another in a vertical direction by a distance corresponding

the span of 192 nozzles. For printing in the 50% overlap mode, all of the nozzles are

used to produce only 50% of the dots (e.g., every other dots).

Thus, in a 50% overlap mode, only 50% of the dots are printed using all of

the ink jet nozzles. The upper one half of the nozzles of the 384 is passed over the

15   printed portions of the band 202 to superpose ink on that band. The lower half of the

384 nozzles supply ink to an unprinted portion of the sheet 4, as represented by band

204 in Figure 2B. As such, the band 202 has been printed with two passes of the

printing device to produce all dots of a given color ink in that portion. In contrast,

only one half of the printed dots of the same color ink associated with the lower band

20   204 in Figure 2B have been printed at this time.

Before a third pass of the printing device 2 over the Figure 2B image, the

print device is again moved vertically downward relative to the sheet by a vertical

distance which corresponds to the height of the original band 202. Next, as

- 13 -

illustrated in Figure 2C, the upper one half of the nozzles in the printing device 2

pass over the previously printed portion of the band 204 to fill in the missing dots of

the given color ink which were not printed when this band 204 was originally

created. The lower half of the nozzles in the printing device pass over an unprinted

5   portion of the sheet to print a first portion of the band 206. Again, only 50% of the

dots (e.g., pixels) of a given color ink are printed in band 206 at this time.

The foregoing process is repeated until the entire sheet has been printed. As

those skilled in the art will appreciate, this process results in the printing heads

associated with each color ink scanning each band of the image twice, using a first

10   set of nozzles of the printing heads associated with a given color to produce a first set

of dots in each band, and using a second set of ink jet nozzles of the printing heads

associated with the same given color to produce a second set of dots in each band

during a second pass. This process is repeated in each band for each color ink. (For

example, after a complete band of magenta has been printed, the band can be

15   successively scanned and printed with cyan, yellow and black ink. thus, for four

color printing, each band is scanned eight times (i.e., twice for each color).

In a 50% overlap mode, every other dot associated with a given location of

the sheet (e.g., each square inch) is printed during a first scan, or pass, over the

sheet. Afterward, the print device or the sheet is shifted vertically by one half of the

20   distance associated with the vertical height spanned by the print device, such that

print device overlaps the previously printed band. During a second pass, the dots

which were not printed in a given band are printed.

During the final pass over the sheet, special treatment which is similar to the

special treatment used during the first scan over the sheet is used. That is, in the

final scan, the entire lower half of all nozzles are deactivated. That is, 50% of the

dots from only the upper half of all nozzles are printed to fill in the missing dots of

5   the last printed band.

Now that the 50% overlap mode of operation has been provided, a brief

review of the 25% overlap mode will be provided. In principle, this mode is similar

to the 50% mode, except that during each of four scans over a band using the print

heads associated with a given color of ink, only every fourth dot is printed. During

10 each of three subsequent passes over a given band of the sheet, another of the four

dots associated with a given color ink is printed in the band. Thus, four scans of the

print device 2 are required to print each band of a sheet with a given color of ink.

To illustrate the 25% mode, reference is made to Figure 3 wherein four bands

of a given color (e.g., magenta) are to be printed. During a first scan, the lowermost

15 one quarter of the ink jet nozzles in the magenta print heads are used to produce a

band having a height which is one quarter the height of a band which could have been

printed if all ink jet nozzles available to print magenta were activated. This is

represented in Figure 3 by the band 302, which represents one quarter of the total

vertical span of the print heads associated with a given color. During the production

20 of the band 302, a first of every four dots in the lower one quarter of the print device

is printed to produce the dots marked "x". Subsequently, the printing device and the

sheet are moved relative to one another by a vertical distance corresponding to one

- 15 -

quarter of the vertical height spanned by all nozzles associated with printing print heads of a given color.

During a second scan, the lower one half of all ink jet nozzles are used for printing. In this lower one half of all ink jet nozzles, the second of every four dots is

5   printed. As such, a band labelled 304 is produced with every fourth dot of the lowermost quarter of nozzles associated with a given color. Another quarter of the nozzles overlap the originally printed band 302. The dots printed in this second scan are labelled "o". Subsequently, the print device and the sheet are moved relative to one another by a vertical distance corresponding to one quarter the vertical height

10   spanned by all nozzles associated with printing a given color.

In the third scan, the third of every four dots is printed to produce a resultant band 306. Note that during this pass, the original band 302 and the original band 304 are overlapped. The pixels printed during this band are labelled "Δ". Afterwards, the print device and the sheet are again vertically moved relative to one

15   another.

During a fourth scan, a fourth of every four dots is printed, as represented in Figure 3 by "σ". Note that in this case, the print device encompasses four bands, and that after this scan all dots of a given color (e.g., magenta) in the first band 302 have now been printed. In band 304, 3/4th of the dots have been printed. In the

20   band 306, one half of the dots have been printed. In the lowermost band 310, only every fourth dot has been printed.

As can be seen from the foregoing discussion, four passes are required to print each band with a given color of ink. This is repeated in the band for each

different color ink. The foregoing process is repeated until the entire sheet has been printed.

Exemplary embodiments of the invention use an overlap mode of operation, such as the 50% overlap mode or the 25% overlap mode described above, to control

5 properly functioning nozzles such that they compensate for malfunctioning nozzles. In a typical non-overlap mode of operation, the print device can be operated at a maximum scanning speed selected on the basis of the maximum firing rate of the ink jet nozzles. Where each nozzle operates in a mode at its fastest rate, this mode cannot be used in accordance with the present invention. That is, where all nozzles

10 are already operating at their maximum firing rate, there is no nozzle available to compensate for a malfunctioning nozzle.

However, in modes of operation wherein the nozzle firing speed is not at its maximum, compensation for malfunctioning nozzles can be implemented. For example, in a 50% overlap mode wherein the scanning speed is the same as that used

15 for the non-overlap mode, only 50% of the maximum firing rate is required for each ink jet nozzle. Accordingly, nozzles can be activated in this mode of operation to fill in for malfunctioning nozzles. However, as those skilled in the art will appreciate, if the scanning speed of the print device is doubled (e.g., increased from 16 inches per second to 32 inches per second), then once again, all nozzles will be required to

20 operate at their maximum firing rate, and no nozzles will be available to fill in for malfunctioning nozzles. As those skilled in the art will appreciate, any ink jet printer having an overlap mode can be used in accordance with exemplary embodiments of the present invention, provided the printer is operated in a mode which does not

require using the entire bandwidth of the print head (e.g., such printers are available from RASTERGRAPHICS, Inc. of San Jose, California, Hewlett Packard of Palo Alto, California, or other similar printing devices).

Thus, exemplary embodiments of the present invention exploit unused

5   bandwidth to compensate for malfunctioning nozzles. In a 50% overlap mode, if one or more of the nozzles is functioning improperly, the ability to completely print a given band is lost. Accordingly, exemplary embodiments of the present invention compensate for this by using either an earlier scan or a subsequent scan to produce not only the dots for the given scan, but also to print those dots which should have

10 been printed in a different scan over the same band, by modifying the control for the print head.

Depending on what nozzle in what head is out, a nozzle in a subsequent or previous band can be used. For example, in a 50% overlap mode, if nozzle 50 in head 6 (from Figure 1A) is malfunctioning, a nozzle 192 nozzle locations away (e.g.,

15 nozzle 242; i.e., nozzle 114 in head 8) can be used to compensate. That is, nozzle 114 of head 8 is in the lower half of the 384 nozzles, and can compensate nozzle 50 during a subsequent scan. Alternately, if the 242 nozzle is malfunctioning, the nozzle 50 of an earlier scan over the band can be used to compensate. In summary, for a 50% printing mode wherein 384 nozzles are used to print a given color ink, the

20 nozzle number which is 192 nozzle locations from the improper functioning nozzle can be used to print both the dots which it was intended to print, as well as the dots which should have been printed by the malfunctioning nozzle during a different scan over the band.

An exemplary implementation of this compensation feature is achieved by
creating a look-up table having a number of entries which corresponds to the number
of nozzles in the print head (or heads) used for each color (e.g., 384 entries for the
Figure 1A print device). In an exemplary embodiment, a look-up table is provided

5   for each scan over a given band. Thus, for four color printing in a 50% mode, eight
look-up tables can be provided (two for each color ink). For four color printing in a
25% mode (where each band is printed using four scans of each color), sixteen look-
up tables can be provided (four for each color).

Each entry of the look-up table includes a mask to control the printing of dots

10   during a given scan. In an exemplary embodiment, a hexidecimal notation can be
used for the masks. For example, a mask shown in Figure 4A can be represented in
the look-up table by the hexidecimal number "55H" (see Figure 5A), where "H"
merely denotes that "55" represents the hexidecimal mask of Figure 4A. The total
number of dots which can be printed in a line across the sheet 4 by an individual

15   nozzle during a single scan across the sheet corresponds to the total number of entries
in the mask or a multiple thereof (e.g., where the mask is repeated within each line).
For a subsequent scan over the same line of the band, the mask would be "AAH" as
shown in Figure 4B. Thus, for a first scan A over any given line of a band, all of the
masks are represented as "55", while for each interleaved scan B over the same line

20   of the band, the mask would be "AA", or vice versa. Where the nozzle used to print
the dots associated with the mask of Figure 4A is malfunctioning, the mask of Figure
4A is "ORed" with the mask of Figure 4B to produce a compensatory mask "FFH"
of Figure 4C. The mask of Figure 4C controls an ink jet nozzle of another scan over

the line of the band so as to print the dots which should have been printed via the

mask of Figure 4A, as well as the dots printed via the mask of Figure 4B.

The look-up table can be stored for each scan, or can be regenerated for each

band, such that there is no need to provide a different table for each scan. Where

5   every other mask is the same (as in a 50% overlap mode), the look-up table can flip

back and forth between the masks for two scans over each band as shown in Figure

5A, wherein the first column illustrates masks for controlling the 384 nozzles

associated with a given color during a first scan over a band, and the second column

illustrates masks for controlling 384 nozzles associated with the same color during a

10   second scan over the band. Figure 5B illustrates a selection of masks which can be

used to create a checkerboard pattern of ink jet nozzle control.

Referring to Figure 5A, assume that a missing nozzle number 50 is detected

which affects the dots printed during the first scan A over a given band. The

contents of the scan B over the band are modified to compensate for this. As such,

15   when the scan B over the band is performed, nozzle number 242 is activated to fill in

for the missing nozzle (i.e., the nozzle 192 locations from nozzle 50). To achieve

this, in line number 242 of the scan B look-up table, an entry is created which

includes the mask of "AA", plus an instruction to activate a nozzle to fill in for the

malfunctioning nozzle (that is, the scan masks "55" and "AA" of Figures 4A and 4B

20   are "ORed" to produce the Figure 4C mask as an entry 242 of the Figure 5A "Scan

B" look-up table. Thus, the scan B mask has been modified.

The scan A mask look-up table must also be modified because in printing

during scan B, nozzle 50 was again inactive. Therefore, in the scan A look-up table,

the scan A mask at location 242 is also compensated for the fact that nozzle number

50 was out during the scan B. To achieve this compensation, the scan A and scan B

masks are again "ORed" to produce the Figure 4C mask for storage of nozzle

location 242 of the scan A look-up table. A similar compensation has been illustrated

5　in the two Figure 5B look-up tables used to implement a checkerboard pattern of dot

printing in a given color. Those skilled in the art will appreciate that look-up tables

associated with the remaining three colors of ink can be similarly produced.

Thus, exemplary embodiments control the output of ink jet nozzles in a

printing device to compensate for malfunctioning nozzles by generating a look-up

10　table of control signals for the nozzles, and by modifying contents of entries in the

look-up table to account for malfunctioning nozzles.

Note that in the 50% mode described above, the look-up table is regenerated

for each scan, and the same entry in both the A scan mask and the B scan mask will

be modified. However, those skilled in the art will appreciate that separate tables for

15　the scan A and the scan B masks can be generated and stored. During printing, the

system can then track which scan mask is currently being used, and then activate the

appropriate look-up table. Note that theoretically, in the 50% mode, one half of the

nozzles can be malfunctioning, and yet 100% of an image can be printed provided a

properly functioning nozzle is located 192 nozzle locations away from all

20　malfunctioning nozzles.

Having described a 50% mode of operation, a 25% mode of operation will

now be discussed. A 25% mode has, in an exemplary embodiment, four look-up

tables for each color ink as shown in Figure 5C. Thus, if a nozzle is malfunctioning,

there are three other scan masks that can be modified to fill in for the malfunctioning

nozzle. Accordingly, malfunctioning nozzles can be compensated for by using a

nozzle in a previous or a subsequent scan that is 96 nozzles away from the

malfunctioning nozzle, or by using a nozzle two scans away (e.g., 192 nozzles) from

5   the malfunctioning nozzle, or by using a nozzle three scans away (e.g., 288 nozzles)

from the malfunctioning nozzle. Further, each of the four look-up tables must be

corrected in a manner similar to that described with respect to compensating for

malfunctioning nozzles in the 50% mode.

For example, consider the mask for each nozzle during scan A is "0X11", the

10 mask for scan B is "0X22", the mask for each nozzle during scan C is "0X44"; and

the mask for each nozzle during scan D is "0X88" as shown in Figure 5C. As those

skilled in the art will appreciate, each of these masks results in one of every fourth

dot being printed during a given scan. However, where a particular ink jet nozzle is

malfunctioning, any of the remaining three scans associated with each printed band

15 can be used to compensate for the malfunctioning nozzle. As such, two nozzles

which are offset by 96 nozzles can be malfunctioning, and still achieve complete

printing.

Having generally described 50% and 25% overlap modes, alternate

embodiments will now be described in accordance with exemplary embodiments of

20 the present invention. One alternate embodiment achieves increased quality by

staggering nozzles which are activated during successive bands in, for example, a

checkerboard pattern as described with respect to Figure 5B. Of course, when a

malfunctioning nozzle is detected, the generated compensation for the table entries

will change accordingly (as described previously). Note that in a 50% mode, the same logic function will result in two entries to the look-up table which will repeat, regardless of whether the checkerboard pattern is implemented or not.

In contrast, in a 25% mode, any number of different patterns can be used. To
5   correct for malfunctioning nozzles in scan B, a revision to the scan A mask is required. Similarly, to compensate for malfunctioning nozzles of scan A, compensation to the scan B mask is required. In scan C, nozzles which could not be printed in scan B can be compensated. Similarly, in scan D, nozzles which could not be printed in scan C are compensated. This is repeated for each of the scans during
10   the printing process. The key is that malfunctioning nozzles in a current scan are compensated in a previous or subsequent scan.

Of course, those skilled in the art will appreciate that in a 25% mode, the scan masks need not repeat every fourth scan. For example, they could repeat every eight band or every twelfth band. Those skilled in the art will appreciate that any
15   desired configuration can be used, it only being necessary that all dots are printed despite the existence of malfunctioning nozzles.

Having described the use of alternate patterns in the look-up table, yet another alternate embodiment of the present invention will be described as a "double strike" mode. The double strike mode is used to print on difficult-to-print surfaces such as
20   vinyl where an ink dot does not spread out very well on the printable medium. In a double strike mode (2), unlike a single strike mode (1), all dots of a band are printed during a first scan. Afterwards, the band is rescanned to create two layers of ink on each dot. As such, the full bandwidth of the print device is required even during a

- 23 -

50% mode. However, if a double strike mode is implemented in a 25% printing mode, then 100% bandwidth is not required and compensation according to the present invention can be implemented. A summary of exemplary embodiments which can be used to implement compensation (comp) of the present invention for

5 nominal speeds (1x) and twice nominal speeds (2x) is set forth in the following table:

SPEED	OVERLAP	STRIKE	COMP	COVERAGE ON LINES WITH MISSING NOZZLES
1x	no	1	no	0%
1x	50%	1	yes	100%
1x	50%	2	no	50%
1x	25%	1	yes	100%
1x	25%	2	yes	100%
2x	50%	1	no	50%
2x	25%	1	yes	100%
2x	25%	2	no	75%

15   Of course, those skilled in the art will appreciate that embodiments of the invention can be varied from the exemplary embodiments described above. For example, as mentioned previously, any print head configuration which can be operated in an overlap mode of operation can be used. Further, any number of print heads and ink colors can be used in accordance with the present invention. In

20 addition, any type of memory can be used to store the masks used to control the ink jet nozzles of the various print heads. For example, a single memory device can be used to store the masks for all print heads. Further, rather than storing a separate mask for every ink jet nozzle as shown in Figure 5A, a single mask could be stored for each of the scan A and scan B print operations. In addition, any masks which

25 have been modified can be stored with an identifier that associates the mask with a

given nozzle. During a print operation, the device controller can track which nozzle should be printing at any given time, and if necessary, access a modified mask for a nozzle whose control has been altered to compensate for a malfunctioning nozzle. Of course, those skilled in the art will appreciate that any of a number of methods for

5 storing scan mask information can be used, and the present information is not limited by the exemplary embodiments of the scan mask storage as described above.

It will be appreciated by those skilled in the art that the present invention can be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The presently disclosed embodiments are therefore

10 considered in all respects to be illustrative and not restricted. The scope of the invention is indicated by the appended claims rather than the foregoing description and all changes that come within the meaning and range and equivalence thereof are intended to be embraced therein.

WHAT IS CLAIMED IS:

1.   Method for controlling ink jet nozzles of a printing device, comprising the steps of:

identifying ink jet nozzles in the printing device which have malfunctioned;
5 and

controlling the output of remaining ink jet nozzles in the printing device to compensate for said malfunctioning ink jet nozzles.

2.   Method according to claim 1, wherein said step of identifying further includes a step of:
10   sequentially activating each of said ink jet nozzles during a test phase of the print device.

3.   Method according to claim 2, wherein said step of sequentially activating further includes a step of:

activating each of said ink jet nozzles for a predetermined period of time.

15   4.   Method according to claim 3, wherein said step of identifying further includes a step of:

correlating an absence of a printed segment at a particular location to a particular ink jet nozzle.

5.   Method according to claim 4, wherein said step of identifying further
20 includes a step of:

simulating line segments printed during said step of sequentially activating said ink jet nozzles on a display.

6.   Method according to claim 5, wherein said step of identifying further includes a step of:
25   storing information which identifies ink jet nozzles which are malfunctioning.

7.   Method according to claim 1, wherein said step of controlling further includes a step of:

operating said printing device in an interleaved mode of operation; and

using said remaining ink jet nozzles in one scan over a printed band to
30 compensate for portions of said band that should have been printed by said malfunctioning ink jet nozzles during another scan over the band.

8.   Method according to claim 7, further including a step of:

repeatedly scanning a printable medium with said printing device in a first direction; and

shifting a relative location of said printing device and said printable medium

5   during each successive scan in a second direction which is perpendicular to said first direction.

9.   Method according to claim 7, wherein said operation is a 50% interleaved mode of operation.

10.   Method according to claim 7, wherein said operation is a 25%

10 interleaved mode of operation.

11.   Method according to claim 1, further including a step of:

storing information for controlling said remaining ink jet nozzles in a look-up table.

12.   Method according to claim 11, further including a step of:

15   regenerating information stored in said look-up table for each scan of said printing device over a printable medium.

13.   Apparatus for controlling ink jet nozzles of a printing device comprising:

a print device controller for controlling an output of ink jet nozzles in the

20 printing device to compensate for ink jet nozzles determined to be malfunctioning; and

a user interface for storing information regarding ink jet nozzles determined to be malfunctioning.

14.   Apparatus according to claim 13, further including:

25   at least one look-up table for storing a mask used to control said ink jet nozzles during a given scan of the print device over a printable medium.

15.   Apparatus according to claim 13, further including:

a display operatively connected with said user interface for displaying information which identifies said malfunctioning ink jet nozzles.

30   16.   A printing system comprising:

at least one print head having ink jet nozzles for printing ink onto a printable

medium;

a print device controller for controlling an output of ink jet nozzles in the

printing device to compensate for ink jet nozzles determined to be malfunctioning;

5   and

a user interface for storing information regarding ink jet nozzles determined
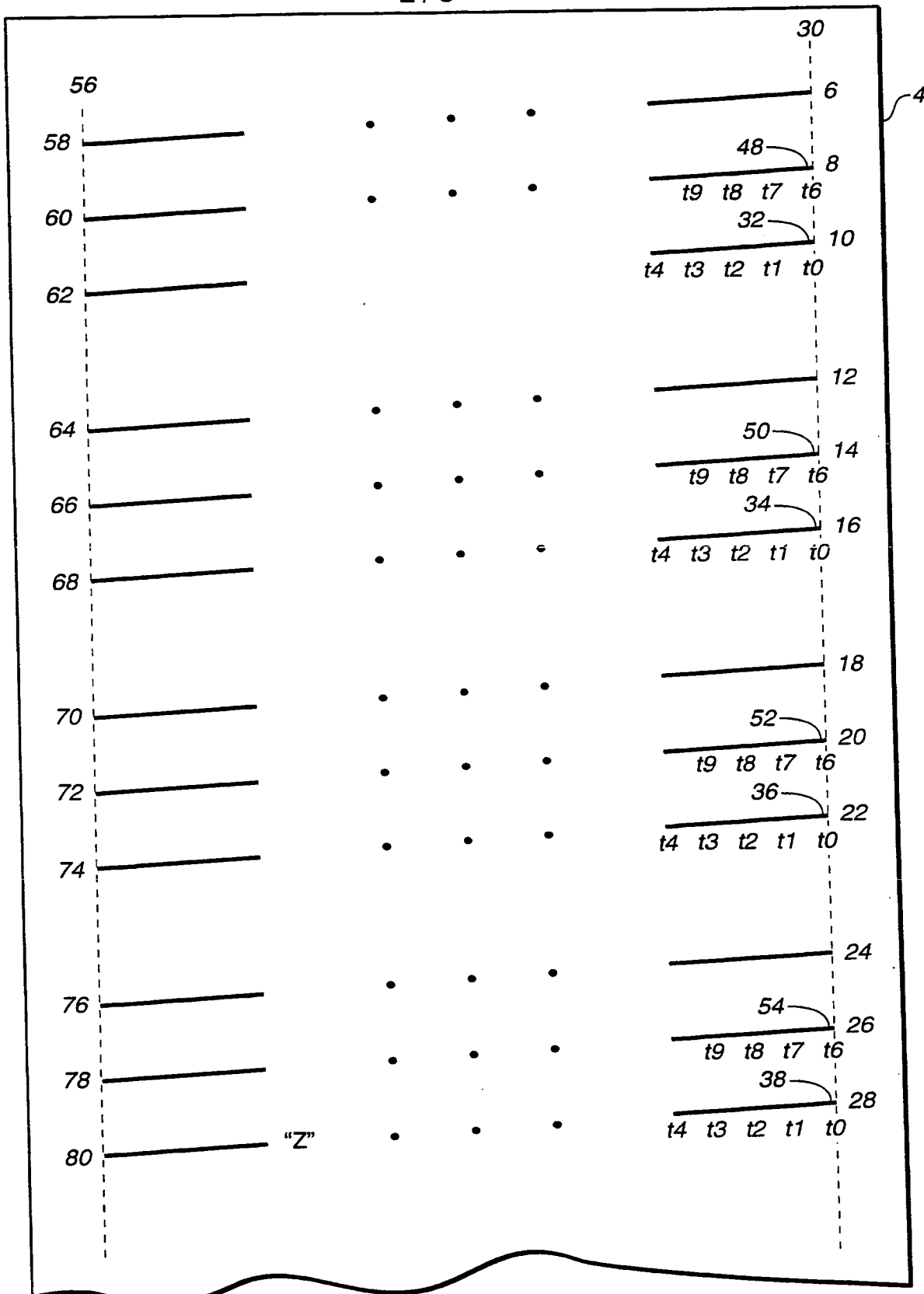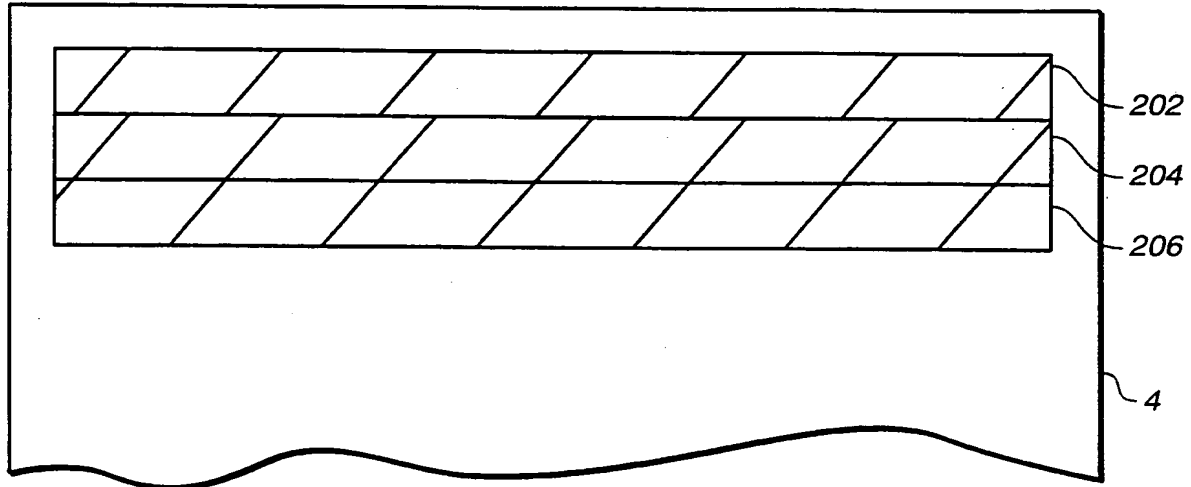
to be malfunctioning.

1 / 5

FIG._1A

FIG._2A

FIG._2B
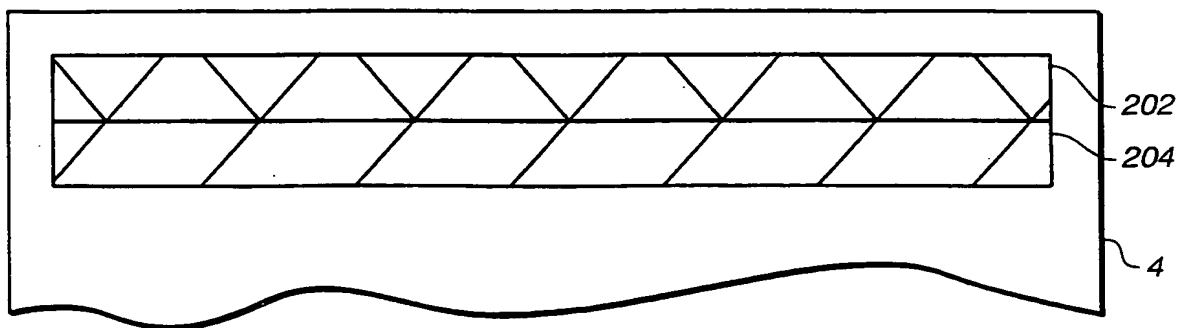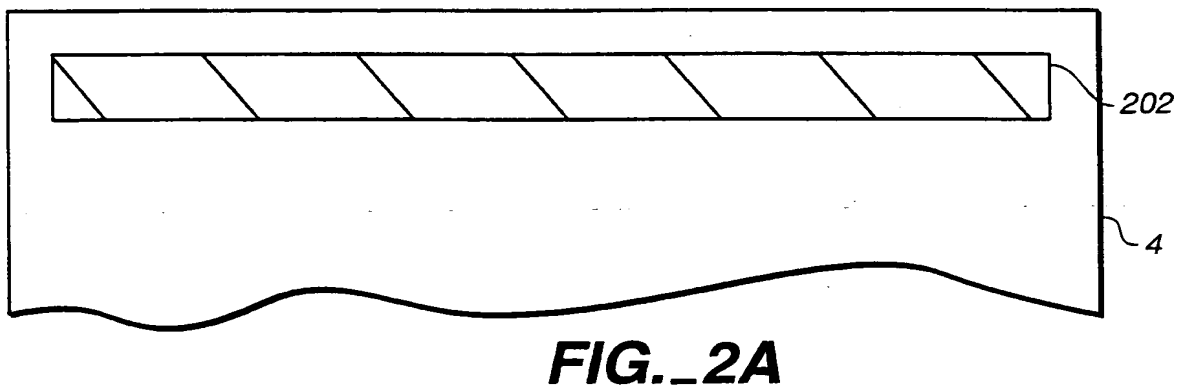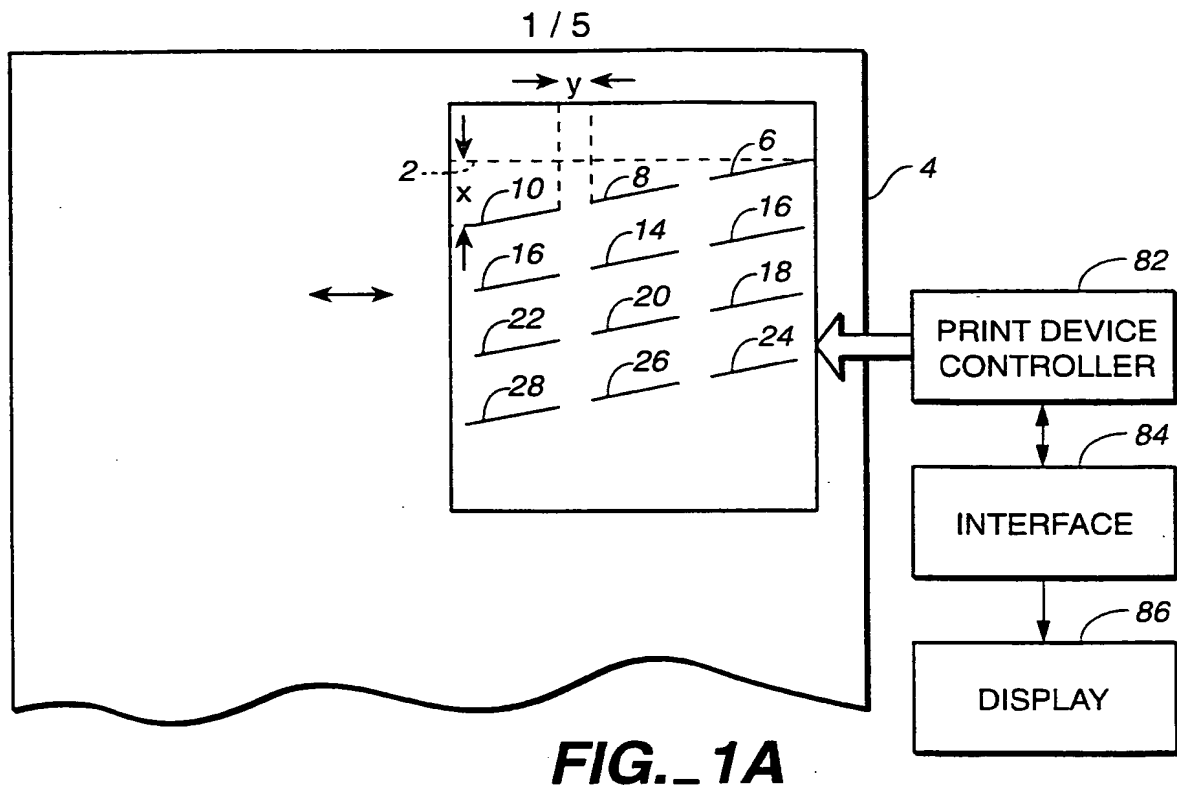
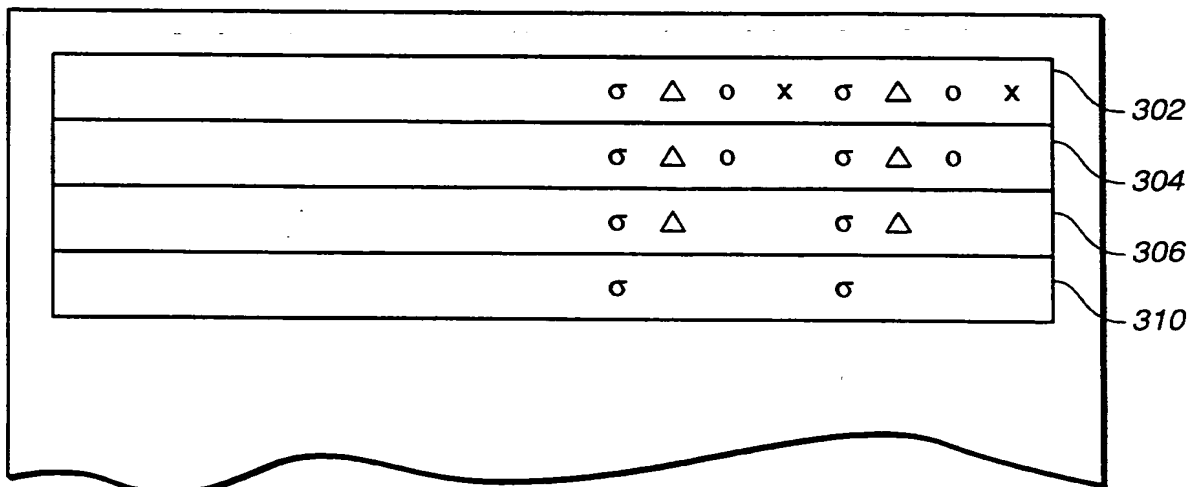**FIG._1B**

FIG._2C

FIG._3

MASK 55

	X		X		X		X		X

FIG._4A

MASK AA

X		X		X		X		X	

FIG._4B

MASK FF

X	X	X	X	X	X	X	X	X	X

FIG._4C

	SCAN A	SCAN B
1	55	AA
2	55	AA
3	55	AA
	• • •	• • •
50	NOZZLE OUT	NOZZLE OUT
	• • •	• • •
242	FF	FF
	• • •	• • •
383	55	AA
384	55	AA

FIG._5A

	SCAN A	SCAN B
1	55	AA
2	AA	55
3	55	AA
4	AA	55
	• •	• •
50	NOZZLE OUT	NOZZLE OUT
	• • •	• • •
242	FF	FF
	• • •	• • •
383	55	AA
384	AA	55

FIG._5B

	SCAN A	SCAN B	SCAN C	SCAN D
1	11	22	44	88
2	11	22	44	88
	⋮	⋮	⋮	⋮
384	11	22	44	88

FIG._5C

INTERNATIONAL SEARCH REPORT

A.   CLASSIFICATION OF SUBJECT MATTER
IPC(6)   :B41J 29/387, 29/393
US CL   :347/19, 41
According to International Patent Classification (IPC) or to both national classification and IPC

B.   FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. :   347/19, 41

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS

search terms: display, test, malfunction, nozzles, orifices, ejectors, look up table, mask

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,124,720 A (SCHANTZ) 23 June 1992, (23.06.97) entire document, especially column 3, lines 35-64.	1 ------ 7-10
X --- Y	US 4,907,013 A (HUBBARD et al.) 06 March 1990, (06.03.90) column 5, line 42 through column 6, line 50; column 7, lines 54-65; column 8, lines 33-50; column 9, line 14-25.	1-4,11 --------- 5-6,12
Y	US 5,572,240 A (SCHMIDT) 05 November 1996, (05.11.96) column 1, lines 18-29 and column 3, line 65 through column 4, line 6.	5-6
Y	US 4,999,646 A (TRASK) 12 March 1991, (12.03.91) column 4, line 63 through column 5, line 40 and Figs. 1-2.	7-10

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

*	Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	
"E"	earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	
"P"	document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 APRIL 1998	1 4 JUL 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	DAVID YOCKEY
Facsimile No. (703) 305-3230	Telephone No. (703) 308-3084

Form PCT/ISA/210 (second sheet)(July 1992)*

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,533,928 A (SUGIURA et al.) 06 August 1985, (06.08.85) column 3, line 62 through column 4, line 7.	12
Y, E	US 5,627,571 A (ANDERSON et al.) 06 May 1997, column 8, lines 47-52.	13-16

THIS PAGE BLANK (USPTO)